Subject: Cavitation

Summary of Discussion

Chairman: Dr. M. Kinoshita
Reporter: Prof. L. C. Burrill
Secretary: Mr. A. Silverleaf

Mr. Emerson discussed the Appendices to the Report in turn. On Appendix 1, he said that basing the tunnel correction on the ratio of disc area to tunnel cross-section area was probably satisfactory for the tunnels normally used, with circular or square cross-sections, but for a tunnel with a rectangular section some equivalent area rather less than the tunnel cross-section should be used. He could not understand why the corrections applied to the spots in Appendix II merely shifted them horizontally. Regarding Appendix III he suggested that in Section V, a separate term should be used to distinguish a regularly pulsating cavity from an unsteady one. For Appendix IV he drew attention to the importance of measuring static pressure as well as velocity in any wake simulated in a tunnel. Finally, he thought that the end of the first paragraph in Appendix VII was misleading in suggesting that because full-scale results had not been sent in, this implied that no cavitation tunnels gave the correct results.

Mr. Vosper commented on the simple cavitation indicator suggested in Appendix VI. He showed results obtained at Haslar on a $3\frac{1}{2}$:1 aspect-ratio foil at 5° incidence and 20 ft./sec. water speed. The cavitation numbers for flashing cavitation in the unattached vortex from the tip, and for the first onset of attached cavitation, were plotted as a function of total air content, and showed a very large scatter. This might be due to variations in the proportion of undissolved air for a given total air content. It would be desirable to have an indicator for which large variations of the inception cavitation number could be obtained.

He doubted whether it was now less essential to specify a standard procedure for tests in uniform flow than in non-uniform flow: the results of Appendix II suggested that the steady flow position was still far from satisfactory.

He welcomed Appendix III, and particularly its proposal to abolish the term "burbling".

Mr. Lindgren showed comparative photographs of cavitation observations on full scale and model propellers. The model tests had been done with a fairly low air content, but with simulation of the wake, and a good overall agreement was obtained, though the full scale tests showed steadier cavitation. This might possibly be due to unsteadiness in the model-scale simulated wake. Two loading cases were illustrated and the blades were in the 15° starboard position. Sheet cavitation round the tip, the tip vortex, and some bubbles in the outer part of the blade were observed. The second and third figures showed the situation for a five bladed propeller on a 68,000 ton tanker. Here the extent of cavitation was limited to a narrow sheet near the tip and a tip vortex. Photographs taken at consecutive angles, 10° - 40°, indicated a maximum extension of the sheet around 20°. At 40° only the tip vortex remains.

Dr. Castagneto said that when the Italian Navy Department recently commissioned a cavitation tunnel, it was decided to undertake comparative tests on a propeller in conjunction with the Rome Tank. The tests were done in open water and in the tunnel at three cavitation numbers, and the agreement between the results were good, as can be seen from the figure.

Mr. Mathews spoke of his full-scale viewing experiences on the measured mile and at sea. He confirmed that good correlation with tunnel results could be obtained, but that correct representation of the wake was necessary, especially for the blade in the upright position on a fine-form single-screw ship. Ideally the correct turbulence level should be simulated as well.

Shaft rake gave rise to important cyclic variations in cavitation, and precise agreement with axial model tests could therefore not be expected.

In model tests of an 8 in. diameter propeller at 20 to 30 ft./sec., 1500-3000 rpm, variations in gas content in the range 0.2 to 0.3 had little effect on visual cavitation patterns, but a considerable effect on noise, which was also affected by speed.

Ship motions could greatly affect cavitation on the full scale, as could struts and brackets just ahead of the propeller, and rudders just behind it. Hydrophone and visual observations of cavitation corresponded well, but the hydrophone method was easier for the observation of inception.

Concerning unsteady propeller forces, Mr. Mathews welcomed Dr. Schuster's paper presenting a non-stationary theory, which justified the quasi-static approach, and opened the way to a calculation of the amplitudes of shaft vibrations. Finally he observed that for a self-propelled model, measurements in the slipstream were at least as important as normal wake measurements without a propeller. (See ref. 53 of Dr. Schuster's paper).

Mr. Bindel said that full-scale experiments had been made in France, not only on propellers but also on bows, bulbs, and appendages, and that the ship and model results were not in such satisfactory agreement as in the cases reported by Mr Lindgren and Mr. Mathews. Although the pattern of cavitation on the ship (deduced from direct observation of the cavitation itself or from the erosion pattern) was often very similar to that on the model, the onset of cavitation nearly always occurred at a mugh higher cavitation number on the full scale than on the model. Thus the full-scale inception speed might be one third lower than that predicted from model tests. This was true even if it was attempted to reproduce the ship conditions in the tunnel. (For example, in the case of the propellers of escort vessels, models were fitted on an inclined shaft, and the tests carried out at an abnormally high air content).

For a bulb, comparative model tests using different experimental techniques had been made at the Admiralty Experiment Works and at the Bassin d'Essais des Carenes, and the results were in good agreement with each other. Model tests could correctly show the way in which shapes of bulbs, etc., should be changed to suppress cavitation on the full scale, and the bow of the lines "France" had been successfully modified as a result of such tests.

Mr. Bindel suggested that some simple-shaped body would be useful for studying ship-model correlation; perhaps an ovoid form could be fitted under the bottom of a ship, in a region of undisturbed flow, and cavitation patterns observed on it and on a model.

He agreed with Mr. Mathews that brackets could have an important effect on cavitation, especially when the ship was turning.

Whilst he supported the proposal of Appendix IV for comparative tests in non-uniform flow, he thought that the programme should be extended to determine not only patterns but also cavitation inception and loss of thrust and torque for different values of J. He thought it would also be useful to have a programme for comparative tests with an inclined shaft.

Prof. Telfer observed that as far back as the 1948 Conference he had suggested that the word 'burble' be dropped. This suggestion had been accepted, so the recommendations of Appendix III were not new in this respect.

He was interested in the report by Bavin and Miniovich on the propulsion of a ship model by cavitating propellers, and in the fact that the thrust deduction became small with cavitation. This was a model result, but there was full-scale evidence to support it, since in the discussion of Col Dondona's 1929 and 1930 INA papers, Prof. Telfer had drawn attention to a reduction in the thrust deduction as soon as cavitation set in.

Contra-rotating propellers had a similar effect in reducing thrust deduction; there was less suction on the rear part of the hull. Thus, naval architects should not regard the thrust deduction as an inescapable evil.

Whilst cavitation at the stern reduced the suctions there, so reducing the drag, cavitation at the bow, of the kind observed by Mr. Bindel, increased the drag by limiting the suctions achieved there.

Concerning Mr. McCarthy's paper, he was uncertain as to the orientation of the grids used to produce the wake. He suggested that an unsymmetrical wake might give the best simulation for a single-screw ship, where the general upflow near the stern meant that on the starboard side the blades of a right-handed propeller operated at a larger angle of incidence than on the port side.

Observing that cathodic protection could greatly minimise cavitation erosion on a full-scale propeller, he suggested that for the study of erosion on the model scale the opposite effect might be exploited, a destructive current being used to accelerate erosion.

Referring to Dr. Castagneto's remarks of the previous day, Prof. Telfer doubted whether the three supposedly geometrically-similar propellers (particularly in view of the very low face pitch ratio of 0.50) were in fact truly similar with regard to their after edges. Study of scale effect using different sized models, and perhaps different tunnel blockages, was always similarly bedevilled with the difficulty of ensuring true similarity. He suggested that a cavitation tunnel could be used to investigate scale effect in non-cavitating flow without involving such difficulties by using a single model and varying water temperature to vary Reynolds number.

Dr. Morgan said that by a development of Mr. McCarthy's methods it should become possible to correct partially for the tangential, as well as to obtain the axial velocity distribution.

Concerning Appendix VII, he wished to say something of recent trials on a twin-screw ship. The propeller blades could (with some discomfort) be observed through glass ports for the part of their revolutions when they were expected to encounter the worst flow conditions. There was a general similarity with the cavitation patterns observed on the model scale, but this was not to say that there was good correlation, particularly with regard to inception. The ship motions, even though small, had an important effect, and the cavitation pattern and especially inception were closely tied to the roll period. Thus a single still photograph of full-scale cavitation might be very misleading; a large number of still shots, or a high-speed cine record, were needed.

Struts and rudders often cavitated at higher local cavitation numbers than propellers, probably due to poor surface finish and to misalignment. Sheet cavitation from a strut in one case broke up into bubbles and passed through the propeller. Such effects might cause cavitation damage on the propeller, and this would be misleading in any correlation between model and full-scale results using the technique of attributing areas of full-scale erosion to locally-generated cavitation.

The water near the propeller was always observed to contain many air bubbles.

Mr. A. Silverleaf, referring to the fact that Dr. van Manen, when presenting his Appendix V, had asked for comments on scale effects on 5-hole yawmeters, said that there were experimental data on such low Reynolds number effects in reports from the National Engineering Laboratory and from Ship Division, National Physical Laboratory.

Dr. Kruppa, in presenting his formal contribution, had said that tunnel wall effects were present. Mr. Silverleaf suggested that the results were also consistent with the view that cavity pressure does not equal vapour pressure, but may depend on the diffusion of gas into the bubble, and hence on tunnel speed, which affects the length of time it takes fluid particles to traverse the length of the cavity along the free streamlines. It was thus very difficult to isolate the effect of a single parameter in tunnel tests.

Mr. Silverleaf agreed with Dr. Hoyt that complete ventilation of cavities was often very difficult. Concerning Mr. Vosper's experiments with the foil used as a cavitation indicator, he suggested that the results were not as erratic as they might seem, but that the onset of cavitation was not a good criterion to work with.

On Mr. Bindel's plea for the use of simple bodies in cavitation correlations between model and full scale, Mr. Silverleaf suggested that bulbous bows already constituted such simple bodies. In a clear sea such as the Mediterranean, bulb cavitation could be observed simply by looking over the side of the ship, and comparisons suggested that model experiments using a fair amount of air in the water gave results in reasonable agreement with full scale.

He admired Mr. McCarthy's work on simulating wakes. Finally, concerning tunnels with resorbers, he thought that they were essential for fundamental research, experiments in them having already shown that cavity pressure may vary with total air content, so that a false picture could be obtained if cavitation number was based on vapour pressure.

Dr. J. W. Hoyt speaking of Appendix III, suggested that, if adopted, it should be printed not only in the Proceedings but also separately, for the convenient use by cavitation-tunnel workers. He thought the word "incipient" could be dispensed with, as it was merely a highbrow way of saying "beginning"; likewise "root vortex" should be replaced by "hub vortex", and "boss" by "hub".

Dr. K. Schoenherr said that the result obtained by Bavin and Miniovich, that thrust deduction tends to zero with full propeller cavitation, was not as startling as Mr. Silverleaf had suggested when introducing their paper. It would be expected that admitting air at atmospheric pressure into the region of the propeller would eliminate any suction effect ahead of it. The situation might be quite different, however, with natural cavitation on the propeller.

Gen. I. Battigelli said that the new Italian Navy Department tunnel was available for any correlation experiments which the Cavitation Committee might suggest.

Prof. A. Nutku said that in Turkey there were no experimental facilities for studying cavitation on the model scale, but plenty of ships with full-scale cavitation on their propellers. It was often found that such propellers were predicted by the standard analysis methods to be free of cavitation. The real flow into the propeller was however far from ideal, especially with ships in the ballast condition. He wondered what the terms "lightly loaded" or "overloaded", applied to propellers really meant. He also thought that the orbital motions in waves would cause significantly different flow conditions for real propellers than those obtaining in experimental conditions in a water tunnel. He wondered how tunnel-wall effect could be properly allowed for in the case of a model propeller with an inclined shaft. He said that he had attempted the converse of trying to simulate a wake in a tunnel, by trying to make a uniform inflow into a ship propeller, using water jets from the stern to counteract the ship wake. After mentioning that tandem propellers in a state of cavitation were difficult to study, he wondered whether the salt in sea water could have a significant effect on cavitation, by affecting the liquid to vapour transition. Finally he observed that ship propeller blades with rough surfaces were found to cavitate more easily than smooth ones.

Mr. J. Strøm-Tejsen referred to the recommendation of Appendix 1 that the Wood and Harris wall-effect correction should be used for propellers in tunnels with solid walls, and asked for suggestions as to the corrections to be used for open-jet or slotted-wall tunnels.

Concerning Appendix II he said that more work was needed to clear up the discrepancies. He agreed with Dr. van Manen's remarks on Appendix V on the unreliability of 5-hole tubes at low Reynolds numbers, and said that in his experience 1.5 metres/sec. was the lower limit of speed for which such instruments could be used. They were not convenient in any case, and he made a plea for the development of some more reliable instrument giving results easier to analyse. Concerning air content, he said that use of the Van Slyke apparatus was not enough; nucleus size should be measured, and he thought the St. Anthony Falls apparatus should be further developed.

Dr. C. Kruppa answering Mr. Silverleaf, said that he had made no attempt to assess wall effect under partly cavitating conditions. Referring to Prof. Nutku's remarks, he said the tunnel-wall effects on propellers with inclined shafts were not yet known.

Prof. L. Mazarredo in reply to Mr. Strøm-Tejsen, said that the discrepancies in Appendix II were not as serious as they might appear. The spots on the figure showed extreme points; corresponding curves might touch or cross each other at other J values, and the differences between them were not so large. The intention of the plotting was merely to show the order of magnitude of the differences found. For this reason, too, only speed, and no pressure or other corrections, was introduced, since the Wood and Harris factors used do not take real wall effects into account. They only correct venturi speed measurement because the theory is only elementary.

It might be useful to suggest, with regard to the Propulsion Committee trials code, that a run should be made at low speed to give a further indication as to the cause of power increases, to determine whether or not they are due to cavitation.

Dr. B. W. McCormick made a written contribution to the report. He had two comments to make to page 3 of Appendix III. He would prefer to see hub vortex cavitation referred to by that name instead of the proposed nomenclature root vortex as he tended to think root as the juncture between the blade and the hub. Also his second comment was with regard to stating the diameter of the core of either tip vortex or hub vortex cavitation. What you observe when you see vortex cavitation is not the core of the vortex, but simply the region in the centre of the vortex where the pressure is sufficiently low to produce cavitation. To him, the core of a vortex implies that region of the vortex where the motion is predominately rotational as opposed to irrotational motion outside of the core.

Prof. L. C. Burrill, concluding the informal discussion, said that several new large tunnels had come into operation since the last Conference, namely, the tunnels at Hamburg, Rome, Japan (where there were three), and at Feltham. Thus there certainly should be many more results for model propellers of large diameter available for the next Conference. Commenting on Appendix 1, which he said had been under fire from some delegates, he said that the results were in the main satisfactory, only the results from one tunnel being a little out. The propeller tested was not one of advanced design, yet its performance with regard to efficiency as well as cavitation was quite good. Finally he thanked Dr. Kinoshita for his able chairmanship of the session.

Dr. J. W. Holl of the Ordnance Research Laboratory, State College, Pa., USA, made a written contribution to the report. In reading it he found that there were many interesting points and very worthwhile ones concerning modern thinking on the subject of cavitation. There were three points that came to mind which he thought should be emphasized.

1. Incipient and Desinent Cavitation

   In several portions of the report, it is indicated that in some cases there are differences between the pressure at which cavitation appears (i.e. "incipient cavitation") and the pressure at which it disappears (i e. "desinent cavitation").

   He thought an effort should be made to distinguish between these two states when referring to cavitation data in order to avoid confusion. Although it is true that in some cases there is little if any difference between desinent and incipient cavitation as far as the pressure is concerned; nevertheless, there are many cases in which the difference is very significant and we should leave no doubts as to the type of cavitation which we are reporting in our descriptions of cavitation research work.

   He therefore recommended using the following terms which he initially recommended several years ago in reference A.

   1. Incipient cavitation is the state where cavitation is beginning to form. Experimentally we obtain this by holding the velocity constant and lowering the ambient pressure from the non-cavitating flow regime until we see the first signs of cavitation. This then is the incipient state.

2. Desinent cavitation is the state where the cavitation has almost entirely disappeared. Experimentally this is found by first lowering the pressure to form a very significant amount of cavitation and then raising the pressure until the cavitation disappears.

The word incipient has been used for a good many years and since the introduction of the term desinent in 1960, this term has had some usage in the United States.

If one desires to refer to both of these states in one group; namely, the state where there are few cavitation bubbles in the flow field, then one might call this "limited cavitation" in accordance with the usage of Dr. M. S. Plesset, reference B.

2. Gaseous Diffusion

As indicated in several places in the report, the importance of gaseous diffusion in the cavitation process is becoming increasingly apparent. Some years ago most models of the inception process were based on the assumption that the bubbles moved with the fluid over the boundary surface. In such cases the diffusion was very slow relative to the vaporization process and so considering the small time available for growth as a bubble moved rapidly through the low pressure region one concludes from this model that diffusion effects are negligible. However, Parkin and Kermeen in reference C report that bubbles often sit on the surface for significant periods of time. Thus the rate of diffusion is increased by several orders of magnitude by the transport effects (reference D). Since such bubbles are stabilized by the pressure gradients on the body one also concludes that the type of pressure distribution should be important (reference A and E).

3. High-Speed Photographic Observations of Cavitation

By far the MOST IMPORTANT POINT which he would like to make was the Importance of High Speed Photographic Observations of Cavitation Phenomena. We are all familiar with the classical work of Knapp and Hollander (ref. F) some years ago and since that time other people have made high-speed photographic observations of the cavitation phenomena. However, in recent years there has not been a great amount of work of this type particularly in the area of incipient and desinent cavitation. It is an appalling fact that the last major research work of this type in the area of incipient and desinent cavitation known to the writer is that of Parkin and Kermeen reference C, and this work was conducted 10 years ago.

Of course, Dr. A. T. Ellis of the California Institute of Technology has introduced in recent years very significant high speed photographic devices and recently has used lasers in his applications (reference G). Dr. Ellis's work has been primarily concerned with bubble collapse and the resultant erosion phenomena. We should follow his lead and utilize these methods in all areas of cavitation research in order to record the detail of the phenomena.

We would be making a great contribution to the furtherance of this field if we would encourage the use of high speed photographic and optical observations of cavitation phenomena. Perhaps a way to initiate this process would be to make a survey of knowledge concerning high speed photographic devices and their applications to cavitation and this information would then be made available to interested laboratories.

References

A. This is reference 4 in the ITTC report.

B. Plesset, M. S., "The Dynamics of Cavitation Bubbles" Journal of Applied Mechanics, Vol. 16, 1949, p.277.

C. B. R. Parkin and R. W. Kermeen, California Institute of Technology Hydrodynamics Laboratory Report E-35.2, Incipient Cavitation and Boundary Layer Interaction on a Streamlined Body, December, 1953.

D. B. R. Parkin and R. W. Kermeen, "The Roles of Convective Air Diffusion and Liquid Tensile Stresses During Cavitation Inception". Presented at the IAHR Symposium on Cavitation and Hydraulic Machinery at Sendai. Japan, September 3-8, 1962.

E. This is reference 2 in the ITTC report.

F. R. T. Knapp and A. Hollander, "Laboratory Investigations of the Mechanism of Cavitation", reprinted from transactions of the ASME for July, 1948.

G. A. T. Ellis and M. E. Fourney, "Application of a Ruby Laser to High Speed Photography," IEEE Journal June, 1963.